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WHITE OAK LABORATORY

# INVESTIGATION OF TECHNIQUES TO REDUCE ELECTROSTATIC DISCHARGE SUSCEPTIBILITY OF HERMETICALLY SEALED EEDS

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3 JULY 1975

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Ten different techniques were investigated to increase the safety of hermetically sealed Navy EEDs to human electrostatic discharge. The application of a conductive coating containing carbon particles called Electrodag®+501 to the back of the initiator plug was found to be the simplest and least expensive of the techniques explored. The coating can protect the EED from repeated discharges and can withstand four weeks of exposure to MIL-STD-331 Test 105.1 with no deterioration.

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INVESTIGATION OF TECHNIQUES TO REDUCE ELECTROSTATIC DISCHARGE SUSCEPTIBILITY OF HERMETICALLY SEALED EEDS

This report describes the results of a project to investigate techniques to increase the electrostatic safety of Navy Electroexplosive Devices. The work was performed under Task Number SF33-354-314/18462.

The results should be of interest to persons engaged in the development, handling, and use of Electroexplosive Devices. The identification of commercial materials implies no criticism or endorsement of these products by the Naval Surface Weapons Center.

J. W. Enig

J. W. ENIG
By direction

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ILLUSTRATIONS

## I. INTRODUCTION

Many Navy electroexplosive devices (EEDs) are susceptible to accidental or unintentional initiation from a human body electrostatic discharge. Increasing use of synthetic fiber clothing, coupled with the difficulty of obtaining recommended cotton clothing, and increasing assembly of EEDs into weapons or test vehicles away from controlled grounded areas can be expected to increase the potential for accidents in future years, unless corrective measures are taken.

The purpose of this project was to investigate techniques to increase the safety of Navy EEDs to a level where they will be immune to human electrostatic discharge. A protective technique was desired which would not make the EED unduly sensitive to other types of accidental initiation (for example, electrically shorting one lead to the case[1] will provide electrostatic safety but will make the EED susceptible to stray currents and crossed grounds). It was also desired to find a technique that would require a minimum of modification to the various EEDs. This report deals specifically with finding a protective technique for hermetically sealed EEDs* (EEDs containing glass-Kovar alloy plugs of the type shown in Figure 1). The Mk 57-1 detonator was used in this investigation as a typical example of this type of EED. See Figure 2.

## II. ELECTROSTATIC DISCHARGE INITIATION MODES

EEDs can be accidently initiated by an electrostatic discharge in the various modes described below:

A. Pin-To-Pin - The electrostatic discharge can travel down one pin (or lead) through the bridgewire and out the other pin. This type of initiation corresponds to normal initiation of the EED as effected by the heating of the bridgewire.

B. Pin-To-Case - The electrostatic discharge can pass through the explosive between the pins and outer case. Very small amounts of energy are necessary for initiation since most primary explosives are easily ignited by an arc discharge.

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[1]Hedden, S. E. and Rossbocker, R. I., "Some Notes on the Navy's Current and Future Requirements on Electric Initiators for Power Cartridges" in the Proceedings of Electric Initiation Symposium, Nov 1960

*A method for electrostatic safing of 1-amp/1-watt no fire device having ribbon bridges has already been worked out. See reference 2. It is not applicable to EEDs having bridgewires of less than 1.0 mil diameter.

[2]Nesbitt, S., "Functioning Time of a 1-Amp/1-Watt Detonator" in the Proceedings of the Sixth Symposium on Electroexplosive Devices, Jul 1969

C. Pin-To-Case (coaxial EED) - The construction of a coaxial EED makes the pin-to-case mode in this type of item correspond to the pin-to-pin mode described above. (The electrostatic discharge travels through the bridgewire between the single pin and the case.)

D. Bridgewire-To-Bridgewire - This type of initiation can occur only in items with dual bridgewires. An electrostatic discharge can jump between the two bridgewires.

## III. TEST METHOD

An electrical circuit is usually used to simulate a human being when determining the sensitivity of EEDs to an electrostatic discharge. There is at present no general agreement on the values to use for the test circuit. The values given in reference 3 appear to be widely accepted and were employed for this investigation. Essentially an RC circuit consisting of a 500 picofarad capacitor charged to 25,000 volts and in series with a 5,000 ohm resistance is used. The switch used was a Kilovac H35 tube. In order for an EED to be considered safe from human body electrostatic discharges, it should not fire when tested with discharges from a test circuit with these parameters. Test voltages other than 25,000 volts were employed where additional information was desired.

## IV. SUSCEPTIBILITY OF MK 57-1 DETONATOR TO ELECTROSTATIC DISCHARGE

The Mk 57-1 detonator has a 0.0008-inch (0.020 mm) diameter nichrome bridgewire approximately 0.055 inch (1.40 mm) in length. Six Mk 57-1 detonators were subjected to a 25,000-volt discharge in the pin-to-pin mode. No initiations were observed. Mk 57-1 type detonators were then made with smaller diameter bridgewires and tested in the same manner. Initiations were not observed until the bridgewire size was decreased to a 0.0004-inch (0.010 mm) diameter. See Table 1. These tests indicate that the Mk 57-1 detonator is quite insensitive to a human electrostatic discharge in the pin-to-pin mode.

Six Mk 57-1 detonators were then subjected to a 25,000-volt discharge in the pin-to-case mode. All six detonators fired. A short Bruceton type test was then run with the voltage as the variable and it indicated that frequent fires will occur at a 5,000-volt level and occasional fires at a 3,000 volt level. See Figure 3. This shows that the Mk 57-1 detonator is extremely susceptible in the pin-to-case mode.

The glass-Kovar alloy plugs of the type used in the Mk 57-1 detonator have a flat surface upon which the bridgewire is mounted. The flat surface is prepared by grinding. During the grinding process small metal particles from the plug eyelet and pins are embedded into the glass surface. These particles can be observed by microscopic examination. Whereas an electrostatic discharge from pin-to-case should statistically occur half the time on the outer surface of the detonator, the small metal particles form a preferential path so that the discharge will almost always take place within the detonator, increasing the pin-to-case hazard.

[3]MIL SPEC MIL-I-23659C, Initiators, Electric; General Design Specification for

## V. INVESTIGATION OF PROTECTIVE TECHNIQUES

The Mk 57-1 detonator has a small cavity on the pin end where the solder seal is made. See Figure 2. This cavity is typically found in hermetically sealed EEDs and is an ideal location for adding protective devices without affecting the external dimensions of the EED. The cavity was utilized for several of the protective materials investigated. A description, results, and comments on the different protective techniques explored are given below in the chronological order of testing.

### Miniature Chip Resistors

In certain detonators such as the Mk 86 and Mk 87, the bridgewire is grounded to the case to prevent accidental initiation by human body electrostatic discharge. This technique can protect the EED in the pin-to-case mode but also makes the EED susceptible to small stray voltages and crossed grounds.* See Figure 4. Because of this susceptibility, a direct short between the bridgewire system and the case was not considered as a protective technique. One method of constructing a preferential path between the pins and case without unduly sensitizing the EED to small stray voltages across the bridgewire is to use a resistor between the pin and case. For example, a resistor of 100 ohms will reduce the current from a 2.5 volt source to 25 milliamperes, a fairly safe level for most EED bridgewires.

One means of inserting a resistance between the pins and case is by the use of miniature chip resistors. The resistors tried in this investigation were Varodyne chip resistors, size 1, 0.050 x 0.050 inch (1.25 x 1.25 mm) with a maximum thickness of 0.025 inch (0.625 mm). They are obtainable in all standard values. In initial exploratory tests, these resistors were soldered on the back of the initiator plug between the pins and case. When a 25,000-volt discharge was passed through the resistor, it was found that the small amount of resistive material on the chip could not handle the discharge and ablated. The resistance value increased so drastically that investigation of this method of protection was terminated.

The resistor method as described would have an additional disadvantage in that the resistor would most likely be soldered onto a loaded detonator. This would possibly entail a precarious operation; also this second soldering operation might affect the previously soldered hermetic seal.

### Miniature Diodes

Miniature diodes were considered as a protective device. These are small semiconductor devices which conduct readily in one direction through a low resistance and present an infinite resistance in the opposite direction.

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*Several accidents have occurred with EEDs protected in this manner when more than one ground was used and the grounds were not at the same potential. Unfortunately one ground was attached to the lead wire not in common with the EED case. When the other ground came in contact with the case (through the EED touching equipment tied to the ground) current could and did flow directly through the bridgewire and between the two grounds. The EEDs initiated with dire consequences.

Breakdown under high voltage can occur in both directions. Initial experiments were run with IN914 diodes. These are too large (0.095 x 0.270 inch [2.37 x 6.75 mm]) to use as protective devices, but were tried to determine the effect of a high voltage discharge. This diode could take the 25,000-volt discharge with no measurable changes in resistance and the result appeared promising enough to try a smaller diode which would fit the Mk 57-1 detonator cavity.

A IN458 miniature diode was chosen. It is 0.020 x 0.020 x 0.004 inch (0.5 x 0.5 x 0.1 mm) in size. A diode would be soldered between each pin and the case. However, since the diode in the conductive direction has a resistance of only approximately 15 ohms, it would make the EED fairly sensitive to a small stray voltage in one direction. To overcome this, two diodes were mounted back to back as in Figure 5a so that an infinite resistance is measured in both directions. Figure 5b shows the method of construction. The small ceramic chip was used as a support mount and the entire assembly was encapsulated in HAPEX 1225R. The assemblies were soldered on an initiator plug and subjected to the electrostatic discharge test. The discharge was found to pass preferentially (as desired) through the diodes rather than on the face of the plug, but unforturnately, each subsequent discharge lowered the original infinite resistance value unpredictably.

Work on this mode of protection was stopped at this time. Besides the unpredictable alteration in resistance, the components, though fairly inexpensive, require a fair amount of hand labor for assembly. Attachment to the detonator would involve the same disadvantages as given for the miniature chip resistors.

<u>Room Temperature Cured Conductive Plastics</u>

Conductive plastics, settable at room temperature, were also tried as a means of inserting a moderate resistance between the pins and case. Two available commercial products were examined - Tecknit carbon/silicone RTV and Emerson & Cumming, Inc., Eccobond conductive adhesive 60L.

Tecknit carbon/silicone RTV is a two-part, semiconductive, carbon-loaded, medium viscosity sealant with a 100 ohm-cm nominal volume resistivity. It has a pot life of approximately four hours after mixing with the catalyst. The material was applied in the pin cavity and cured at room temperature for 24 hours. The material was sluggish and difficult to apply, but adhered well in the cavity. The material protected the Mk 57-1 detonator from a pin-to-case electrostatic discharge. The detonators with this material in the cavity were subjected to MIL-STD-331 Test 105.1 (Temperature and Humidity) for four weeks. After the test, the plastic still had good adherance and the detonators passed the 25,000 volt discharge test. The resistance of the conductive plastic was observed to drop after the discharge test, increase during temperature and humidity exposure, and drop again after the second discharge test.

Eccoband conductive adhesive 60L is a two-part, carbon-based, conductive adhesive with a 50 ohm-cm nominal volume resistivity. The material has a paste-like consistency and is difficult to apply, but not quite as difficult as the RTV. The material adhered well in the cavity and protected the Mk 57-1 detonator from a pin-to-case electrostatic discharge. The detonators were then subjected to four weeks of MIL-STD-331 Test 105.1. The material adhered well but its resistance increased drastically (initial average of 1,000 ohms to an average of 115,000 ohms). The detonators still passed the electrostatic discharge test, with the average resistance dropping to 20,000 ohms.

Both conductive plastics were considered satisfactory for the protection of EEDs, with preference being given to the RTV because of its smaller resistance changes.

High Temperature Cured Conductive Plastic

Another conductive plastic evaluated for use with EEDs was Eccobond conductive adhesive 60C. It is a one-part conductive adhesive with a volume resistivity of 50 ohm-cm. The material must be cured at an elevated temperature and the minimum recommended curing temperature is 149°C. This temperature is higher than the loaded detonator can withstand so that this material has to be applied to an inert part before the explosive is loaded.

Two holes of 0.040 inch (1 mm) diameter were drilled with a carbide tipped drill in each glass-Kovar alloy plug as shown in Figure 6. The material was forced in the holes with some difficulty and was cured at 225°C for 20 minutes. Resistance measurements can be made before the plug is used as a subassembly. Ten initiator plugs prepared in this manner were assembled in Mk 57-1 detonators. All 10 detonators were then subjected to four weeks of MIL-STD-331 Test 105.1. Very little resistance change was observed and all detonators again passed the 25,000 volt discharge test. The very small changes in resistance ($\bar{x}$ = 685 ohms before test, $\bar{x}$ = 675 ohms after test) can probably be attributed to two factors:

(1) curing at an elevated temperature is better for stabilization, and

(2) the plastic material is hermetically sealed within the detonator.

The two room temperature settable conductive plastics previously described were also tried in this technique, but could not be utilized. Evidently gases emitted during the catalyzing cause separations in the plastic column so that a measurable resistance cannot be obtained. The technique has the disadvantage that the carbide tipped drills used to make the holes in the initiator plugs wear rapidly during the drilling process and require frequent replacement (every 20 drill holes). This makes the drilling process fairly expensive. Glass seal manufacturers were contacted to determine if the holes could be preformed during manufacture of the initiator plug, but the feeling was that the holes could best be added by a secondary operation such as drilling.

Photoetched Ribbon Bridge Element

A ribbon type bridge element has been used in the Mk 101 detonator to give a 1-amp/1-watt insensitive detonator and to also protect the detonator in the pin-to-case mode.[2] See Figure 7a. The explosive is loaded only on the central portion of the ribbon and the sawtooth patterns around the perimeter of the element provides a relatively safe discharge path from the bridge element to the cup or case away from the explosive. The technique to date has only been used on 1-amp/1-watt no fire EEDs, and the purpose of this investigation was to determine if it could be adapted for more sensitive EEDs.

Photoetching companies were contacted to determine to what degree the ribbon portion could be reduced. In general, with nichrome, a width down to three times the material thickness can be photoetched. The thinnest nichrome sheet presently obtainable is 0.0005 inch (0.0125 mm) and using the rule of thumb given above, the cross sectional equivalent of a 1-mil (0.025 mm) diameter wire or larger can be made using this technique. The bridgewire in the Mk 57-1 detonator is 0.0008 inch (0.02 mm) in diameter and is too fine to be reproduced in this manner. Therefore, the technique cannot directly be used to match the Mk 57-1 detonator sensitivity. There are variations of this technique which might however be employed. The sawtooth points could be plated on the glass plug surface, and the bridgewire fastened in the conventional manner. This type of variation was investigated with materials on hand. Mk 101 photoetched bridge elements were mounted on the glass initiator plug and the ribbon portion cut off. An 0.0008 inch (0.02 mm) wire was then mounted as shown in Figure 7b. The nylon charge holder was modified as shown in Figure 8b so that the spark would take place away from the explosive. This modification necessitates the use of a smaller amount of lead azide. Detonators constructed in this manner, though able to pass the electrostatic discharge test, could not meet the explosive output requirement. The substitution of RD 1333 lead azide for dextrinated (Figure 8c) did not improve the output, but the modified charge holder shown in Figure 8d enables this design to just meet the output requirement. Forty two detonators made in this manner passed the 25,000 volt discharge test. The technique with the photoetched ribbon bridge can be employed directly as a replacement for wire sizes 1-mil (0.025 mm) or larger in diameter, provided that the EED design can be modified so that the discharge takes place away from the explosive.

One contract for silk screening silver points directly on the glass plug so that any size wire can be soldered was unsuccessful. See Figure 9. An epoxy base silver mixture was used and the epoxy burned off. The silver was successfully deposited on the glass but could not be held to the desired tolerances. Other variations of this technique can be tried, but were not explored at this time. These could include deposition of the points, or a pattern, on the insulation disc sometimes used adjacent to the bridgewire. See Figure 10.

## Bleeder Resistor

Detoronics Corporation, South El Monte, California, has developed a technique to make a bleeder resistor as an integral part of the glass Kovar metal initiator plug. Molybdenum is dispersed in a glass matrix and by several high temperature processing operations is incorporated into the intitiator plug. See Figure 11. The plugs are trimmed by a series of high voltage discharges to give a value of 6,000 - 40,000 ohms between the pins and case. The material has a negative temperature coefficient and during discharge drops to a low dynamic resistance in microseconds providing a preferential path exterior to the explosive.

Initiator plugs of the Mk 57-1 detonator design were ordered from Detoronics Corporation for trial. A lot of twenty Mk 57-1 type detonators was built using these plugs. During assembly of the detonator, the average pin-to-case resistance was observed to double from 26,000 to 51,000 ohms. Five more detonators were assembled and the pin-to-case resistance checked after each operation to determine if any particular assembly operation was responsible for the resistance charge. See Figure 12. Apparently the conductive material is pressure sensitive with random resistance changes occurring after each operation. The glass Kovar metal initiator plugs used for the Mk 57-1 detonator are required to have a glass to sleeve strength of 300 lbs. This strength is slightly weakened with the addition of the bleeder material, and tests indicate that the sleeve strength requirement would have to be relaxed to 250 lbs if the bleeder plugs are employed.

The twenty five Mk 57-1 detonators with the bleeder resistor plug were subjected to the electrostatic discharge test. One detonator fired during the test. Figure 13 shows the resistance changes observed. The resistance of the detonator that failed was an average value and prior radiographic examination showed no anomaly. Although only one of twenty five detonators failed the electrostatic discharge test, the failure to ascertain the cause and the unpredicatable resistance changes led to the decision to terminate investigation of this technique.

Coherer Materials

Materials which exhibit a high resistance at firing voltages, but which have a low resistance at voltages of the magnitude of electrostatic discharge have been proposed for many years as a protective measure for electrostatic discharges. U.S. Patents 2,480,124 and 2,480,125 tell of the use of galena, stibnite, carborundum, yellow crystalline iron pyrites, and zincite as protective materials. Finely powdered metals such as silver, nickel, iron, brass, copper, and aluminum flake were also found to give the same effect. Silicon carbide in a silicone binder was recently found to protect the Mk 15 Actuator from electrostatic discharge.[4]

Three shunt mixes of this type were investigated for their ability to protect the Mk 57-1 detonator.

| | |
|---|---|
| (1) silicon carbide/silicone binder (RTV 615) | 23/11 |
| (2) aluminum flake/silicone binder (RTV 615) | 11/11 |
| (3) atomized aluminum/silicone binder (RTV 615) | 16/11 |

The silicon carbide (320 grit)/RTV 615 mix was made in the 23/11 proportions given in reference 4. The mixture was very thick and had to be thinned with xylene for application to the cavity of the Mk 57-1 detonator. Two of five detonators treated in this manner fired during the electrostatic discharge test. The same experiment was repeated using a 1-micron silicon carbide and, as expected, the results were worse with six of six detonators failing the electrostatic discharge test. To determine if the protection of the Mk 15 Actuator could be duplicated, the 320 grit mix was applied to ten Mk 15 Actuators. All ten passed the electrostatic discharge test. The pin-to-case electrostatic susceptibility

[4]Fyfe, D. and Schroeder, H., Final Report on Characterization of an Antistatic Shunt Mix, Unidynamics Document No. MTR-24, 28 May 1969.

of the Mk 15 Actuator was then investigated and found to be in the 20,000-volt region. It appears that this type of shunt mix can protect an item with a high pin-to-case internal breakdown voltage (ca 20,000 volts), but would be marginal for an item with a low pin-to-case internal breakdown voltage (ca 3,000 volts) such as the Mk 57-1 detonator, even if a slightly larger grit of silicon carbide was used.

Both aluminum mixes were found to be unsuitable for protection as the first electrostatic discharge through the mix was likely to produce a short between the pins and case. This could result in a failure of the item to function due to the loss of a large portion of the firing signal. The silicon carbide mix, when successful as a protective technique, was not permanently changed by the electrostatic discharge and could protect against multiple discharges without affecting the reliability of the item. The use of coherer materials did not offer much in the way of an advantage over previously evaluated techniques and so were only briefly investigated at this time. Larger grit sizes of silicon carbide can be used to give lower breakdown voltages, but the upper grit size will be limited by the small gap between the pin and case and the uniformity of the breakdown voltage.

## Electrodag®

Acheson Colloids Company has recently developed a new line of conductive coatings called Electrodag®. Investigation of the coatings showed that Electrodag® + 501 with a resistance of 1,000 ohms/square at a 1-mil (0.025 mm) thickness gave the desired resistance isolation between the pins and case of a glass-Kovar initiator plug. Electrodag® + 501 is a combination of specially processed carbon particles in a resin system that can withstand temperatures up to 500°F (260°C). It is a one component mixture which cures at room temperature and can easily be applied to a Mk 57-1 detonator with an artist's paint brush.

Ten Mk 57-1 detonators were painted with Electrodag® + 501. The resistance between the pins and case ranged from 550 to 990 ohms with an average value of 735 ohms. All ten detonators passed the electrostatic discharge test. After the test, the pin-to-case resistance values ranged from 280 to 520 ohms with an average value of 410 ohms. Materials containing dispersed carbon as the conductive material typically show a resistance drop after subjection to the electrostatic discharge test.

To find the effect of multiple electrostatic discharges, twelve Mk 57-1 detonators with the Electrodag® + 501 coating were subjected to 10 consecutive electrostatic discharge tests with the pin-to-case resistance checked after each test. All twelve detonators passed the 10 electrostatic discharge tests. The resistance changes observed are shown in Figure 14 for four of the twelve detonators tested. It can be seen that the Electrodag® + 501 will protect the detonator against multiple electrostatic discharges with the first or second discharge essentially determining the resistance decrease.

To determine the effect of temperature and humidity on the adherance and protective value of the Electrodag® + 501, thirty Mk 57-1 detonators were prepared with the conductive material. During the early testing, it was noticed that the Electrodag® + 501 could be scraped off if a sharp edge were inserted into the painted cavity. It was thought that a coat of protective material over the conductive material would make removal extremely difficult. Therefore, fifteen of the thirty detonators were also coated with TUF ON[R] #74 varnish. This type of material has been used for many years as a sealant for nonelectric explosive components. The thirty detonators were subjected to an electrostatic discharge test after application of the coatings, and all passed the test. The detonators were then subjected to four weeks of MIL-STD-331 Test 105.1. The Electrodag[R] + 501 and varnish protected Electrodag[R] + 501 both adhered well with small changes in resistance. Detonators with the protective varnish coat had smaller resistance changes then the unvarnished detonators. All thirty detonators passed a second electrostatic discharge test after the temperature and humidity exposure.

The screening tests with the Electrodag[R] + 501 appeared very favorable. The coating protected 52 out of 52 detonators in the electrostatic discharge test, was not affected by multiple electrostatic discharges, required no design changes, passed temperature and humidity exposure, and was the least expensive of the techniques explored. Since it appeared fairly unlikely that a simpler and less expensive technique would be available at this time, it was decided to run engineering design tests to learn more about the technique and find if it had any limitations that would preclude its adoption.

## VI. ENGINEERING DESIGN TESTS

### Electrostatic Discharge Penalty Test

Ten detonators were prepared with the Electrodag[R] + 501 and protective varnish coat. All ten were subjected to the electrostatic discharge test and passed. The detonators were then subjected to a second more severe electrostatic discharge test in which the series resistance was reduced from 5,000 to 2,500 ohms. All ten passed this overtest. The detonators were then subjected to a third electrostatic discharge test in which the series resistance was reduced to 500 ohms. Seven of ten detonators fired on this third test. It appears that there is an adequate margin of safety for meeting the design goal for protection from a human body discharge, but the technique should not be considered as protection for charges of a greater magnitude.

### Resistance Limits

The resistance of the Electrodag[R] + 501 coating can be adjusted by either mixing with other Electrodag[R] products or by controlling the thickness of the applied layer. In this investigation, only the thickness of the layer was varied. Firing circuit designers had indicated that a resistive protection technique should provide at least 100 ohms isolation from the pins-to-case so that only an insignificant percentage of the firing energy would be lost. With resistance values originally ranging from 210 to 990 ohms, five of the fifty two detonators tested dropped slightly below 100 ohms (94, 95, 96, 99, 99 ohms) after passing the electrostatic discharge test. Originally these detonators had values in the 200-300 ohm range, so it appears that an applied initial value of at least 300 ohms would be desirable.

In order to determine an upper resistance limit, thin coats of Electrodag[R] + 501 were applied to thirty detonators. The detonators were subjected to the electrostatic discharge test and then a second more severe electrostatic discharge test to determine the upper resistance limit. See Table 2. The resistance drops after the electrostatic discharge test are more severe than previously observed with lower initial resistances. On the basis of the results in Table 2 and previous observations, it appears that an initial application range of 300 to 2,000 ohms be suggested and a final resistance range of 100 to 1,250 ohms be permitted after undergoing a screening electrostatic discharge test. Further experience may show that the upper limit can be safely raised.

The failure of the initial application of Electrodag$^{R}$ + 501 to fall within the desired range does not mean loss of the detonator. The material can be washed off with methyl ethyl ketone when the resistance is too low and another coat applied. A second thin coat can be applied to make the layer thicker if the resistance is too high.

## Protective Coatings

Scotchcast Resin No. 8 was investigated for use as a protective coating for the Electrodag$^{R}$ + 501 in addition to TUF ON$^{R}$ #74 varnish. The Scotchcast was applied over the conductive material on fifteen detonators and allowed to cure at room temperature. The application of the Scotchcast tended to increase the resistance of the Electrodag$^{R}$ + 501. All fifteen detonators passed the electrostatic discharge test and were subjected to four weeks of MIL-STD-331 Test 105.1. The Scotchcast adhered well and very little change in resistance was observed. The fifteen detonators were then subjected to a second electrostatic discharge test and all again passed the test.

Forty Mk 57-1 detonators painted with Electrodag$^{R}$ + 501 were used to determine whether Scotchcast No. 8 or TUF ON #74 varnish was the better protective coat, and to decide whether the protective coat should be applied before or after the electrostatic discharge test. Twenty detonators were first subjected to an electrostatic discharge test and then ten of these were coated with Scotchcast and ten with varnish. Of the remaining twenty, ten were first coated with varnish and ten with Scotchcast before the detonators were subjected to an electrostatic discharge. Table 3 shows the results. The final resistances of all items were in an acceptable range and all items passed the electrostatic discharge test. In general, the application of a protective coat over the Electrodag$^{R}$ + 501 tends to increase the resistance of the Electrodag$^{R}$ + 501 with Scotchcast producing a greater increase than the varnish. It appears that either material can be used as a protective coat if desired. The test indicated no preference as to whether the protective coat should be applied before or after the electrostatic discharge test. Intuitively, the electrostatic discharge test should be the last test run with the resistance of the conductive coating checked after the test for the proper resistance limits.

## Firing Energy

All resistance measurements of the Electrodag$^{R}$ + 501 coating were made in the pin-to-case mode. To determine the pin-to-pin resistance, ten glass-Kovar initiator plugs without bridgewires were given a coat of Electrodag$^{R}$ + 501. Measurements showed that the pin-to-pin resistance will be approximately double that of the pin-to-case resistance. This would mean that there would be approximately 200 ohms in parallel with the bridgewire when the pin-to-case resistance was at the minumum 100 ohm level. This means that under the worst conditions (8 ohm bridgewire), a maximum of 4% of the firing energy can be lost in the conductive coating.

A Bruceton test was run with Mk 57-1 detonators coated with Electrodag$^{R}$ + 501 to determine if the conductive coating had a discernable effect upon the firing energy. The test showed that the 50% firing level was less than that of unmodified Mk 57-1 detonators. This indicates the conductive coating has little or no effect on the firing energy at a 25 volt level. All no-fires from the Bruceton test fired at the Mk 57-1 detonator specification level of 3.75 microfarads charged to 40 volts. In spite of these results, it is recommended, as a matter of caution, that the protective coating not be employed where the firing energy is marginal.

## VII. DISCUSSION

The Navy inventory of EEDs consists of many diverse designs and configurations developed for specific weapon applications. The majority of these EEDs, except for the recently developed 1-amp/1-watt items such as the Mk 101 detonator, are susceptible to accidental initiation by human electrostatic discharge. The varied designs make it difficult to develop a single protective technique which can be easily retrofitted to all EEDs and therefore, different techniques are needed for different designs. This report deals specifically with finding a protective technique for hermetically sealed EEDs.

There were three design goals in this investigation. The first design goal was to incorporate a protective technique so that currently used EEDs can pass the 500 picofarad, 25,000 volt, 5,000 ohm electrostatic discharge test, in which case the EEDs can be considered insensitive to human body electrostatic discharge. The second design goal was that the technique should not make the EED unduly sensitive to other accidental types of initiation. The third design goal was to minimize any dimensional or functional requirement changes in the EED, so that weapon modifications would not be required. The Electrodag$^{R}$ + 501 technique meets these three design goals.

Other techniques were considered for protection in addition to those described in this report. Some of the techniques are more amenable to incorporation in the design of new EEDs than for retrofit to existing items. They are briefly discussed below.

(1) Spark insensitive explosives - Boron and other ingredients have been added to primary explosives to reduce the spark sensitivity. This method was not considered because the additive materials can affect the sensitivity and hence the firing energy of the EED. Expensive qualification in accordance with OD 44811 would also be required. This would not be desirable for a retrofit of an EED which has a specified firing requirement.

(2) Spark-gap outside primer cavity - A spark gap is used to provide a preferential breakdown path so the electrostatic discharge will take place away from the explosive. This concept has been used in the primer cavity with the Mk 101 detonator. Commercial blasting caps have utilized a protective spark gap inside the long plug. However, initiator plugs on Navy EEDs are much

smaller and not readily adaptable for an inside spark gap. External spark gaps are not too desirable since they can be circumvented by unanticipated contaminations that might conceivably increase the dielectric strength.

(3) Insulation - This involves the placement of a dielectric barrier strong enough to prevent an electrostatic discharge from taking place. The use of this method is not feasible with the glass-Kovar plugs used in hermetically sealed EEDs. The method can be employed in other types of EEDs.

(4) Conductive glass - This involves the substitution of conductive glass for the glass presently used in the initiator plug to provide a preferential discharge path. At this time, there is no available commercial source for a glass compatible for sealing with Kovar and conductive throughout its volume. However, glass can be coated with a conductive material (metallic oxides) which can be fired to the glass. Industrial experts did not consider the coating process feasible for the intiator plug.

(5) Varistors - A new varistor material, principally zinc oxide and bismuth oxide, called MOV is effective in suppressing high voltages developed from electrostatic charges. MOV will break down at a set voltage and have a very low dynamic resistance. The adaption of MOV will require the insertion of a disc of the material or some type of modification of the initiator plug. The material is still under experimental investigation at other agencies for use as an EED protective technique against electrostatic discharge.[5]

The level of safety given by the Electrodag$^R$ + 501 coating will protect against inadvertent initiation of EEDs by human electrostatic discharge in all but the most unusual circumstances*. The coating should not be relied upon for protection against more energetic electrostatic discharges such as might be obtained from helicopter potentials, plastic sheets, lightning, etc. Drastic redesign and desensitization of present EEDs would be necessary if more stringent requirements are imposed.

Adoption of the Electrodag$^R$ + 501 technique involves the abandonment of the insulation resistance requirement employed for many years with EEDs. EEDs are frequently tested with an overvoltage in excess of the normal firing potentials to measure the insulation resistance. This type of testing is performed to show up failures or incipient failures in insulation with the usual requirement being that the resistance value be greater than 50 megohms at a D.C. potential of 325 or 500 volts. This is a nondestructive test and it is proposed that this test be replaced with a measurement of the Electrodag$^R$ resistance (after electrostatic discharge testing) which would also be a nondestructive procedure.

[5]Menichelli, V., "Metal Oxide Varistors to Reduce the Hazards of Electrostatics to Electroexplosive Devices," presented at the American Defense Preparedness Association Meeting, St. Louis, Mo., Oct 1974

[6]Vance, E. F., Seely, L. B., and Nanevicz, J. E., "Effects of Vehicle Electrification on Apollo Electro-Explosive Devices," Final Report SRI Project 5101, Dec 1964

*Where body resistance and capacitance have little to do with the energy delivered to the EED during handling.[6]

Certain weapons require that the firing circuit not be tied to the weapon case to prevent any cross connections or HERO* problems. If the minimum of 100 ohms isolation is not sufficient for a specific weapon, the EED can be electrically isolated by either of the techniques shown in Figure 15. The isolation will not affect the human electrostatic protection. Appendix A discusses the use of resistance padding as a protective technique.

## VIII. CONCLUSIONS

A technique to increase the safety of hermetically sealed EEDs to human electrostatic discharge has been developed. The technique is applicable to the Mk 155-0 primer, Mk 11-0 squib, Mk 57-1, Mk 57-2, Mk 74-0, Mk 75-0, Mk 84-0, Mk 85-0, Mk 90-0, Mk 94-0 detonators, Mk 3-0, Mk 4-0, Mk 15-1 actuators and devices containing the aforementioned actuators such as the Mk 1-0, Mk 11-0, Mk 12-0 drivers and Mk 35-0, Mk 46-0, Mk 94-0, Mk 95-0, and Mk 96-0 switches.

*Hazard of Electromagnetic Radiation to Ordnance.

TABLE 1

EFFECT OF BRIDGEWIRE DIAMETER ON PIN-TO-PIN ELECTROSTATIC DISCHARGE*
SUSCEPTIBILITY IN MK 57 DETONATOR CONFIGURATION

| | Bridgewire Diameter | | | |
|---|---|---|---|---|
| Test Number | 0.0008 inch (0.02 mm) | 0.0006 inch (0.015 mm) | 0.0005 inch (0.0125 mm) | 0.0004 inch (0.01 mm) |
| 1 | No Fire | No Fire | No Fire | Fired |
| 2 | No Fire | No Fire | No Fire | Fired |
| 3 | No Fire | No Fire | No Fire | Fired |
| 4 | No Fire | No Fire | No Fire | Fired |
| 5 | No Fire | No Fire | No Fire | Fired |
| 6 | No Fire | No Fire | No Fire | Fired |

*500 pF, 25,000 volts, 5,000 ohms

TABLE 2

DETERMINATION OF UPPER ELECTRODAG$^{R}$ + 501 RESISTANCE LEVEL FOR PROTECTION OF MK 57-1 DETONATORS

| Detonator | Initial Resistance Pin-to-Case | Electrostatic Discharge Test | Resistance After Test | Penalty Electrostatic Discharge Test* | Resistance After Test |
|---|---|---|---|---|---|
| 1 | 1100 | Passed | 580 | Passed | 430 |
| 2 | 1260 | " | 590 | " | 410 |
| 3 | 1320 | " | 620 | " | 450 |
| 4 | 1320 | " | 650 | " | 460 |
| 5 | 1330 | " | 630 | " | 470 |
| 6 | 1440 | " | 730 | " | 590 |
| 7 | 1540 | " | 760 | " | 600 |
| 8 | 1550 | " | 700 | " | 500 |
| 9 | 1660 | " | 700 | " | 480 |
| 10 | 1700 | " | 700 | " | 520 |
| 11 | 1750 | " | 890 | " | 760 |
| 12 | 1830 | " | 820 | " | 610 |
| 13 | 2000 | " | 770 | " | 550 |
| 14 | 2190 | " | 840 | " | 630 |
| 15 | 2260 | " | 1960 | " | 1900 |
| 16 | 2330 | " | 770 | " | 540 |
| 17 | 2360 | " | 920 | " | 680 |
| 18 | 2420 | " | 1040 | " | 750 |
| 19 | 2480 | " | 1670 | " | 1500 |
| 20 | 2480 | " | 2120 | " | 2040 |
| 21 | 2840 | " | 1030 | " | 710 |
| 22 | 2910 | " | 1970 | " | 1760 |
| 23 | 2930 | " | 980 | " | 810 |
| 24 | 3440 | " | 1350 | Fired | -- |
| 25 | 3880 | " | 1350 | " | -- |
| 26 | 3980 | " | 1540 | " | -- |
| 27 | 4670 | Fired | -- | -- | -- |
| 28 | 11,410 | Passed | 5120 | Passed | 4660 |
| 29 | 18,430 | " | 5830 | " | 5260 |
| 30 | 35,000 | Fired | -- | -- | -- |

*2,500 ohm resistor substituted for 5,000 ohm resistor

TABLE 3

COMPARISON OF PROTECTIVE COATINGS

| Detonator | Initial Resistance Pin-to-Case | Electrostatic Discharge Test | Resistance After Test | Resistance After Varnish Coat | Resistance After Scotchcast Coat | Electrostatic Discharge Test | Resistance After Test |
|---|---|---|---|---|---|---|---|
| 1 | 550 | Passed | 330 | 360 | | | |
| 2 | 570 | " | 330 | 340 | | | |
| 3 | 1350 | " | 720 | 750 | | | |
| 4 | 840 | " | 440 | 480 | | | |
| 5 | 890 | " | 510 | 520 | | | |
| 6 | 910 | " | 530 | 580 | | | |
| 7 | 720 | " | 400 | 430 | | | |
| 8 | 1130 | " | 510 | 550 | | | |
| 9 | 1280 | " | 550 | 590 | | | |
| 10 | 10200 | " | 440 | 460 | | | |
| 11 | 550 | " | 320 | | 450 | | |
| 12 | 660 | " | 360 | | 490 | | |
| 13 | 1390 | " | 690 | | 1230 | | |
| 14 | 780 | " | 440 | | 680 | | |
| 15 | 890 | " | 460 | | 700 | | |
| 16 | 900 | " | 460 | | 780 | | |
| 17 | 1050 | " | 480 | | 700 | | |
| 18 | 1120 | " | 440 | | 740 | | |
| 19 | 1260 | " | 560 | | 940 | | |
| 20 | 700 | " | 330 | | 450 | | |

TABLE 3 (CONTINUED)

COMPARISON OF PROTECTIVE COATINGS

| Detonator | Initial Resistance Pin-to-Case | Electrostatic Discharge Test | Resistance After Test | Resistance After Varnish Coat | Resistance After Scotchcast Coat | Electrostatic Discharge Test | Resistance After Test |
|---|---|---|---|---|---|---|---|
| 21 | 680 | | | 630 | | Passed | 490 |
| 22 | 720 | | | 790 | | " | 340 |
| 23 | 730 | | | 770 | | " | 340 |
| 24 | 860 | | | 880 | | " | 400 |
| 25 | 910 | | | 960 | | " | 390 |
| 26 | 900 | | | 990 | | " | 410 |
| 27 | 1020 | | | 1070 | | " | 420 |
| 28 | 1060 | | | 1130 | | " | 520 |
| 29 | 1200 | | | 1300 | | " | 480 |
| 30 | 1320 | | | 1370 | | " | 500 |
| 31 | 580 | | | | 1300 | " | 620 |
| 32 | 690 | | | | 1080 | " | 390 |
| 33 | 730 | | | | 1160 | " | 450 |
| 34 | 850 | | | | 1380 | " | 420 |
| 35 | 880 | | | | 1260 | " | 440 |
| 36 | 930 | | | | 1420 | " | 500 |
| 37 | 1060 | | | | 1730 | " | 580 |
| 38 | 1060 | | | | 1650 | " | 520 |
| 39 | 1210 | | | | 2090 | " | 610 |
| 40 | 1290 | | | | 2210 | " | 640 |

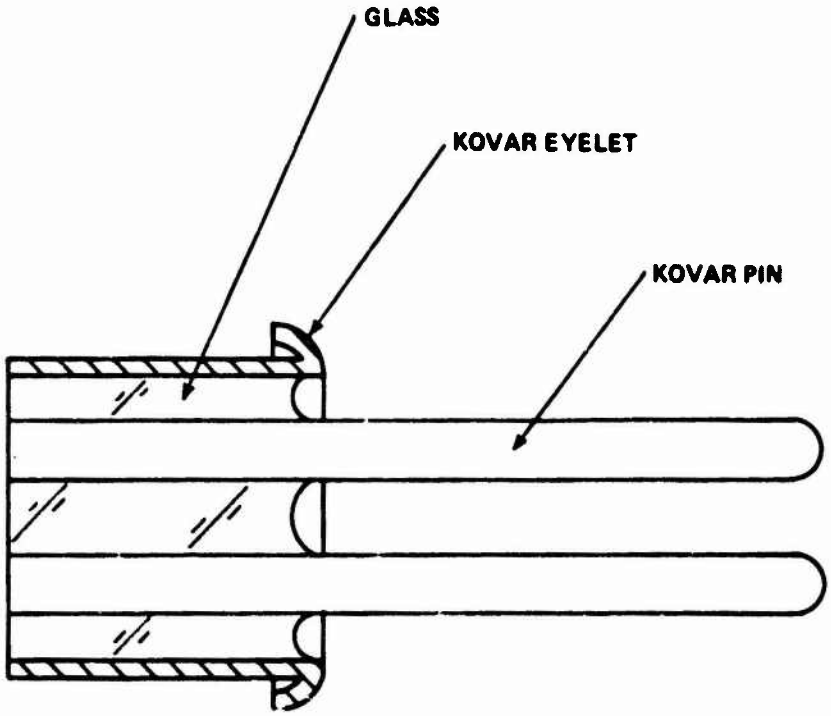



FIG. 1 INITIATOR PLUG

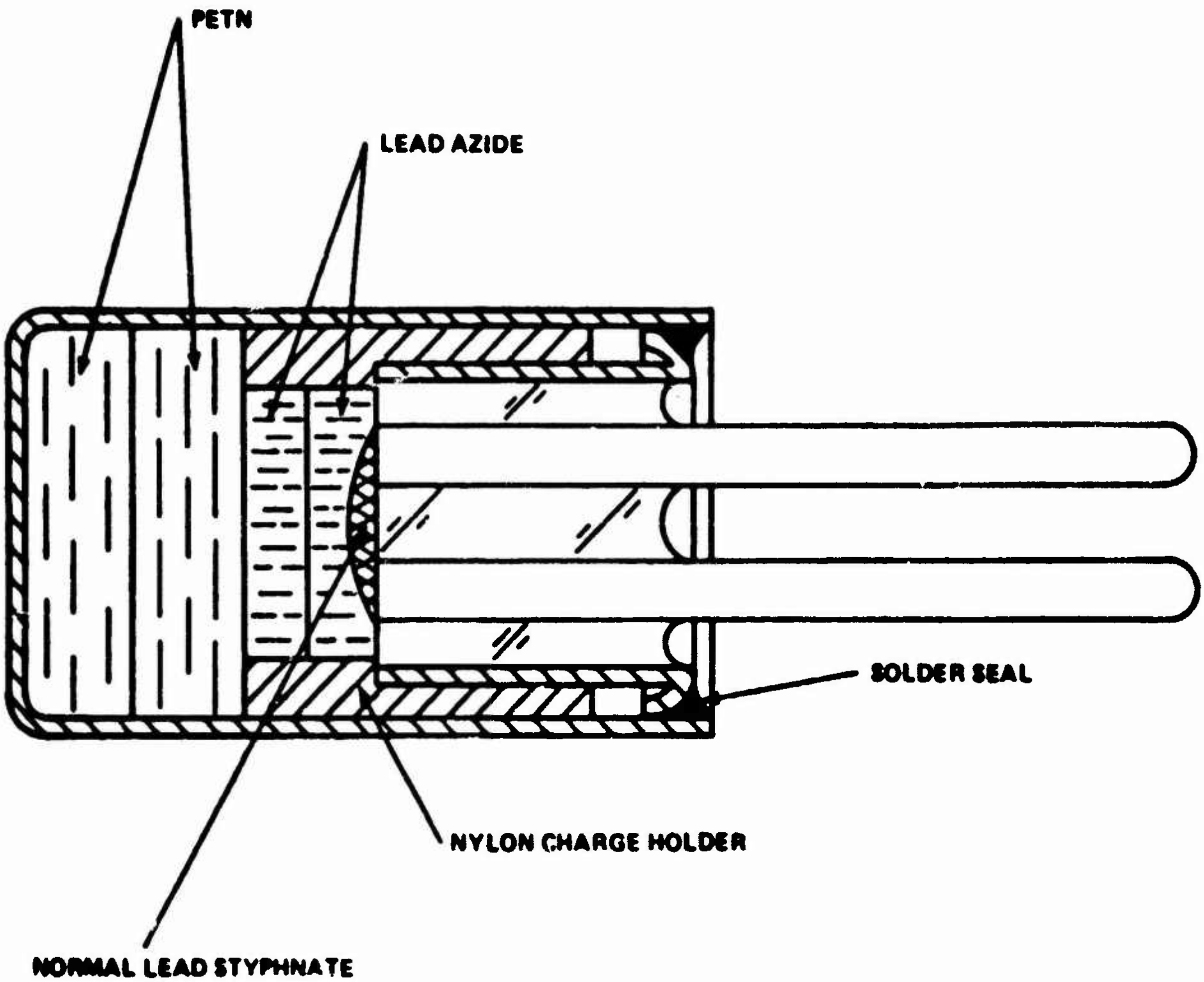



FIG.2 MK57 MOD 1 DETONATOR

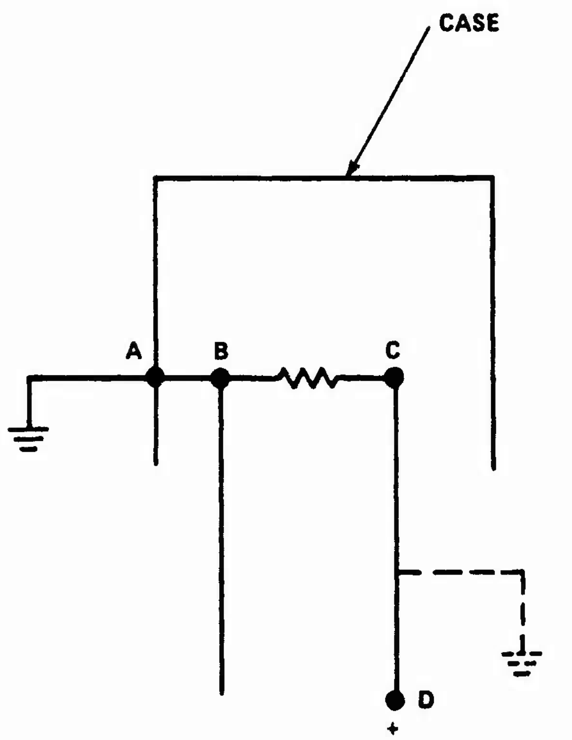
| Voltage Level | Shot no. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 7000 volts | | x | | | | | | | | |
| 5000 volts | 0 | | x | | | | x | | x | |
| 3000 volts | | | | x | | 0 | | 0 | | 0 |
| 1000 volts | | | | | 0 | | | | | |

X=Fire

O=No Fire

* 500 pf, 5000 ohms

FIG. 3 PIN-TO-CASE ELECTROSTATIC DISCHARGE* SUSCEPTIBILITY OF MK 57-1 DETONATOR



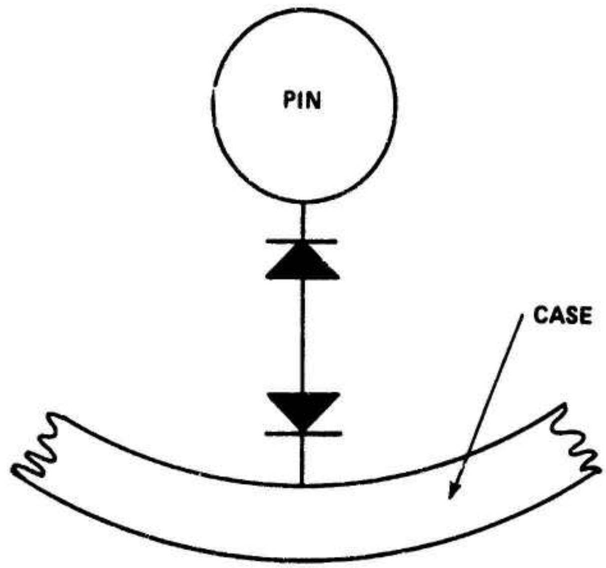

To protect EED's from a pin-to-case electrostatic discharge, a short is sometimes used between points A and B.

When this mode of protection is employed, a small stray voltage i.e. (2.5 volts) between points A and D can effect a 0.5 ampere current flow through the bridgewire (BC). Stray voltages have been introduced by cross grounding when two grounds have been used in complex arrangements. Unwittingly the two grounds were not at the same potential.

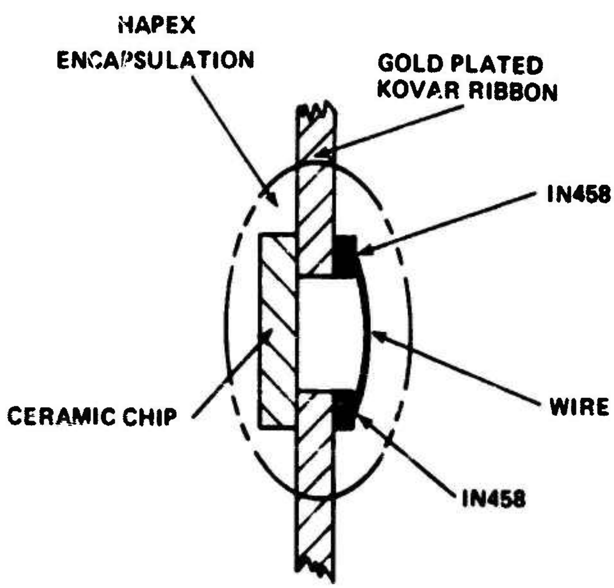
$$I = \frac{E}{R} = \frac{2.5}{5} = 0.5 \text{ ampere}$$

Typical bridgewire resistance (BC) $\cong$ 5 ohms

FIG. 4 POSSIBLE DANGER FROM SHORT BETWEEN AN EED BRIDGEWIRE AND CASE




(a)




(b)

FIG. 5 METHOD OF MOUNTING DIODES

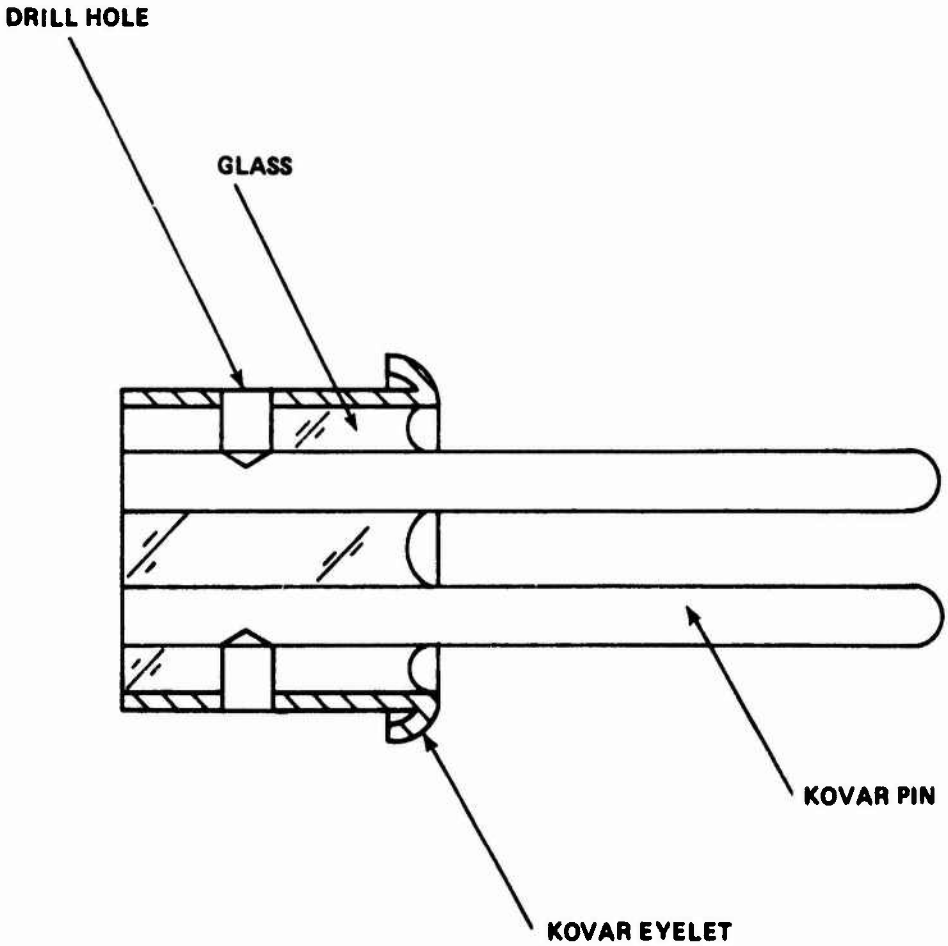
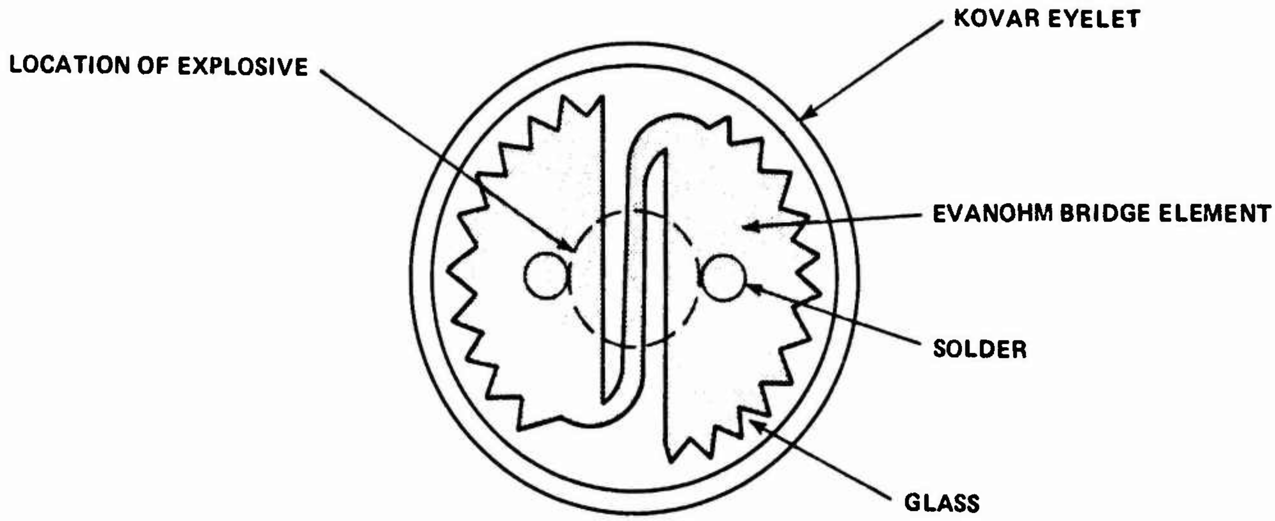
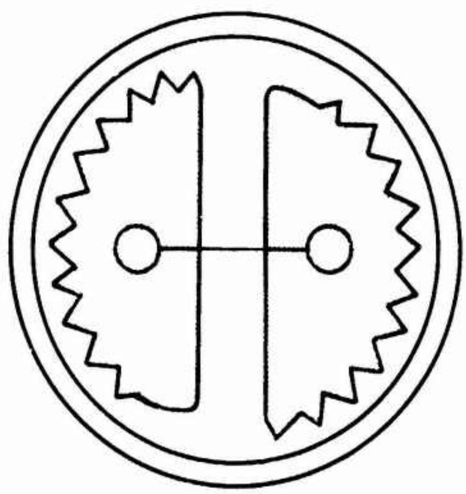



FIG. 6 LOCATION OF DRILL HOLES




a) MK 101 DETONATOR BRIDGE ELEMENT



b) MODIFIED BRIDGE ELEMENT

FIG. 7 PHOTOETCHED RIBBON BRIDGE ELEMENT

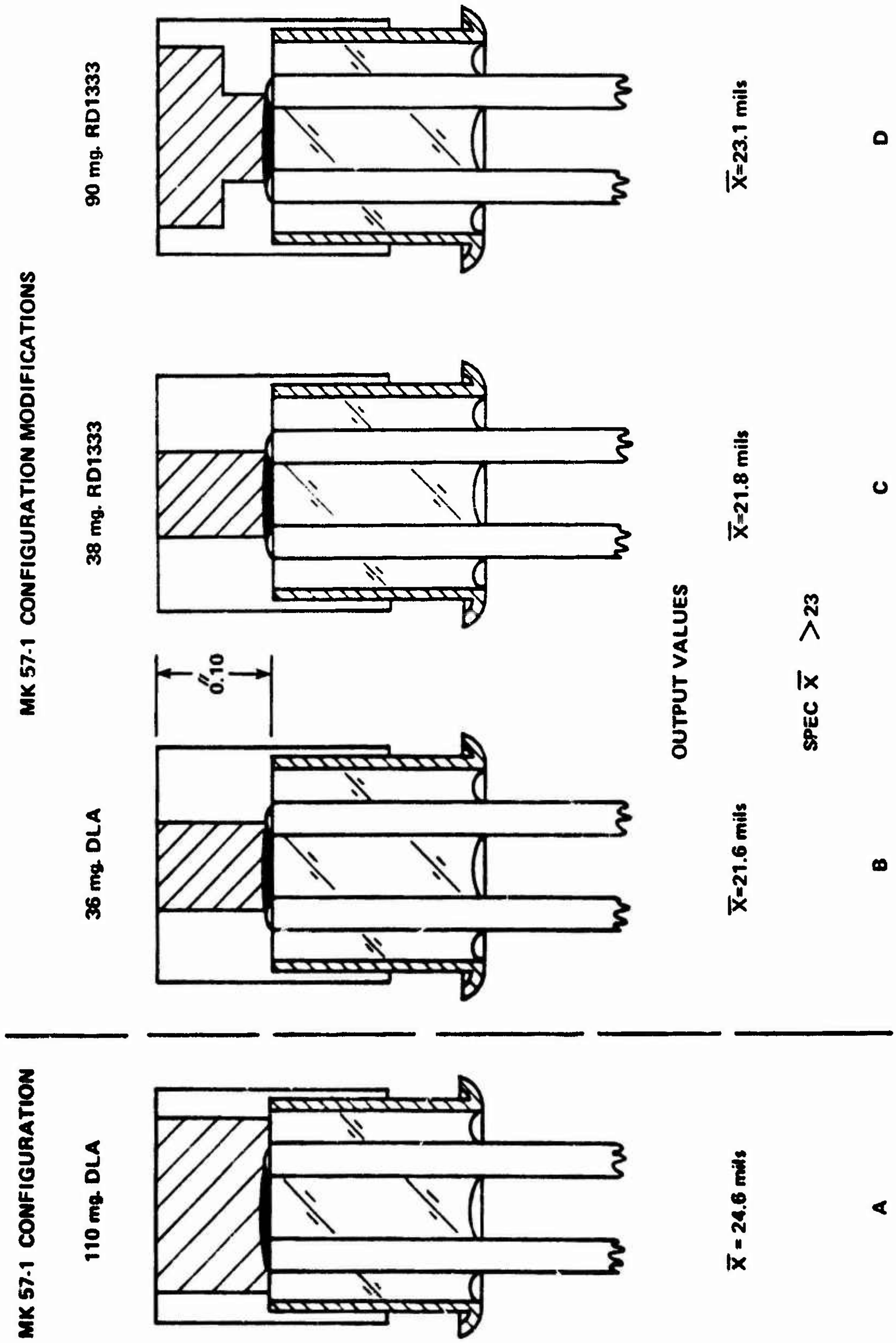



FIG. 8 EFFECT OF CHARGE HOLDER MODIFICATION ON MK57-1 DETONATOR OUTPUT

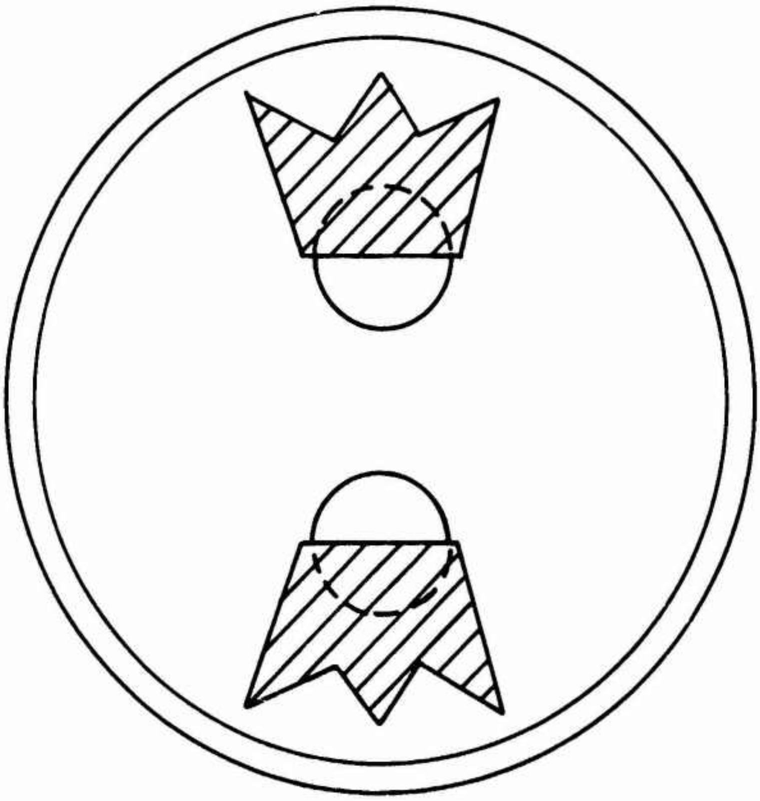


FIG. 9 PATTERN FOR FILM DEPOSITION

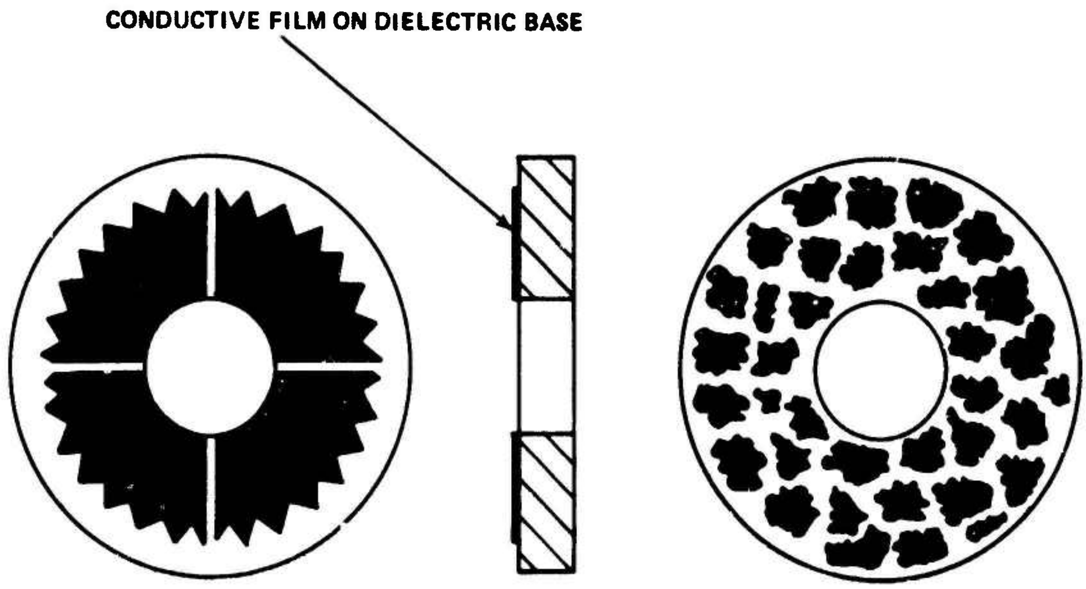



FIG. 10 POSSIBLE PATTERNS FOR ELECTROSTATIC DISCHARGE PROTECTION

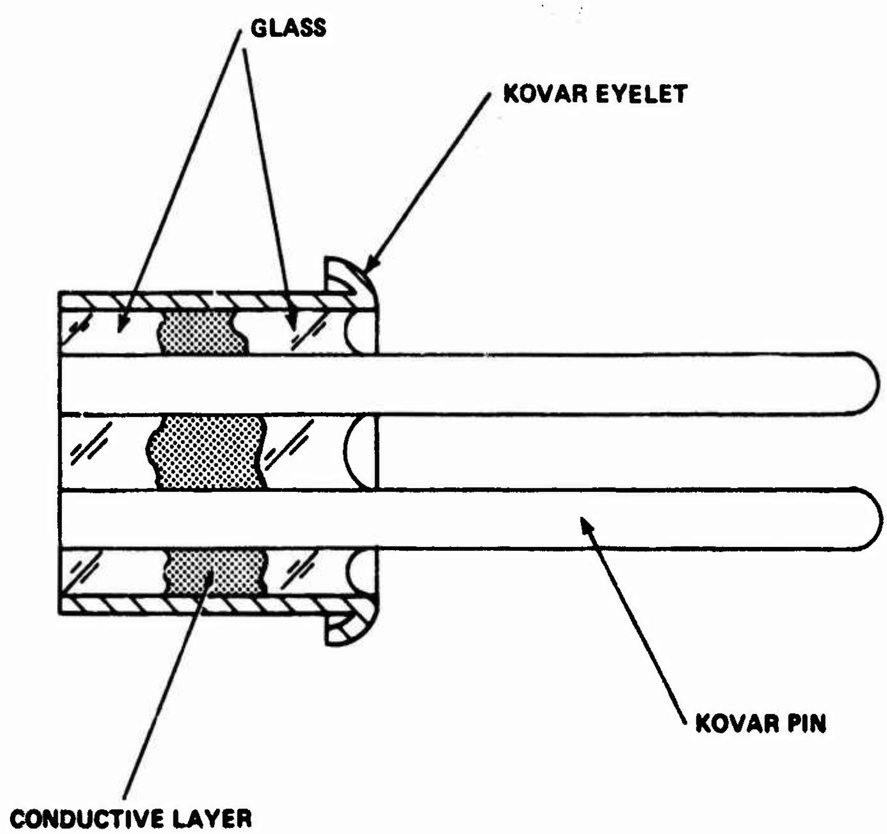



FIG. 11 CONDUCTIVE LAYER INITIATOR PLUG

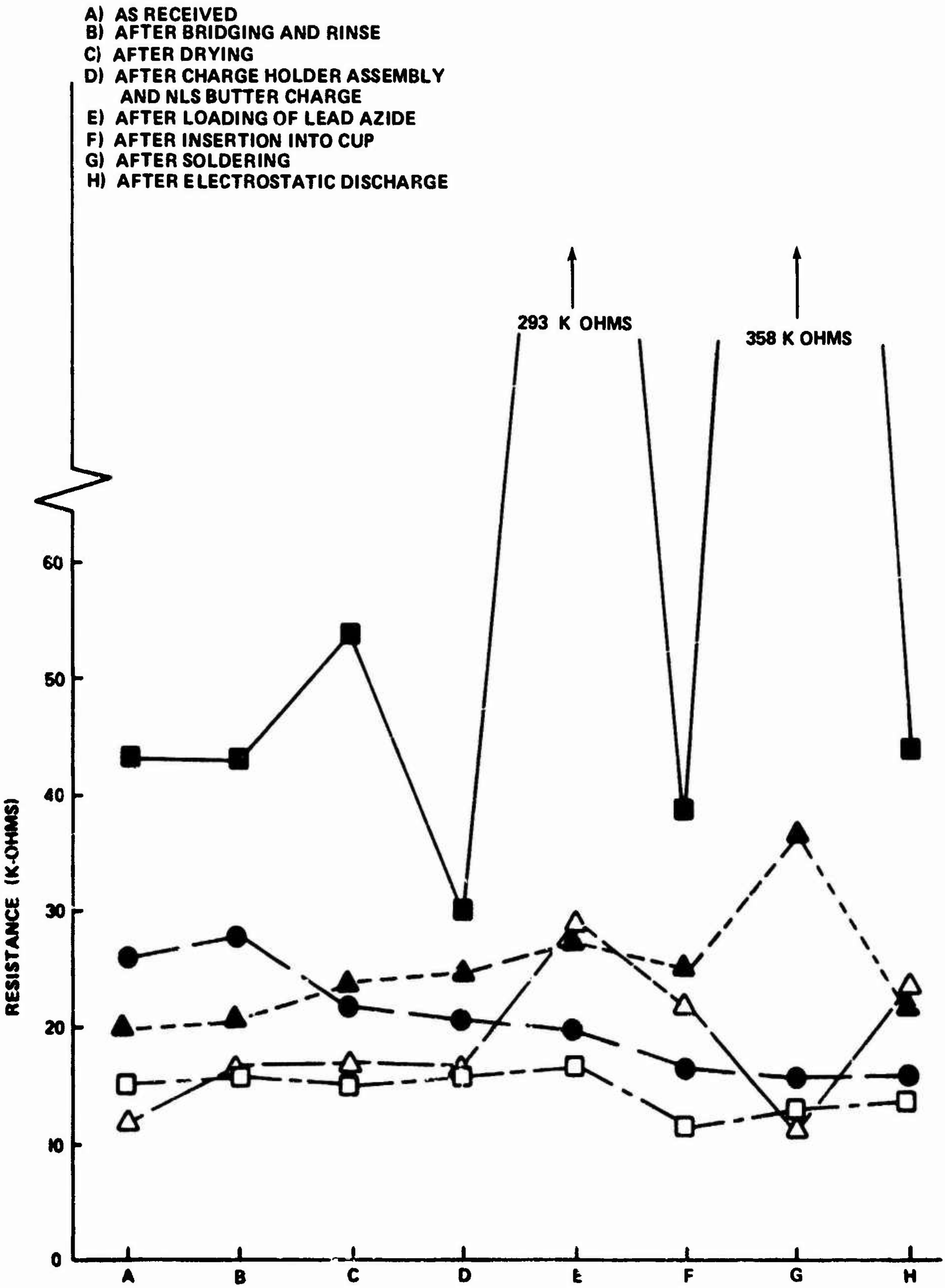



FIG. 12 EFFECT OF ASSEMBLY OPERATIONS ON RESISTANCE OF DETORONIC BLEEDER RESISTOR PLUG

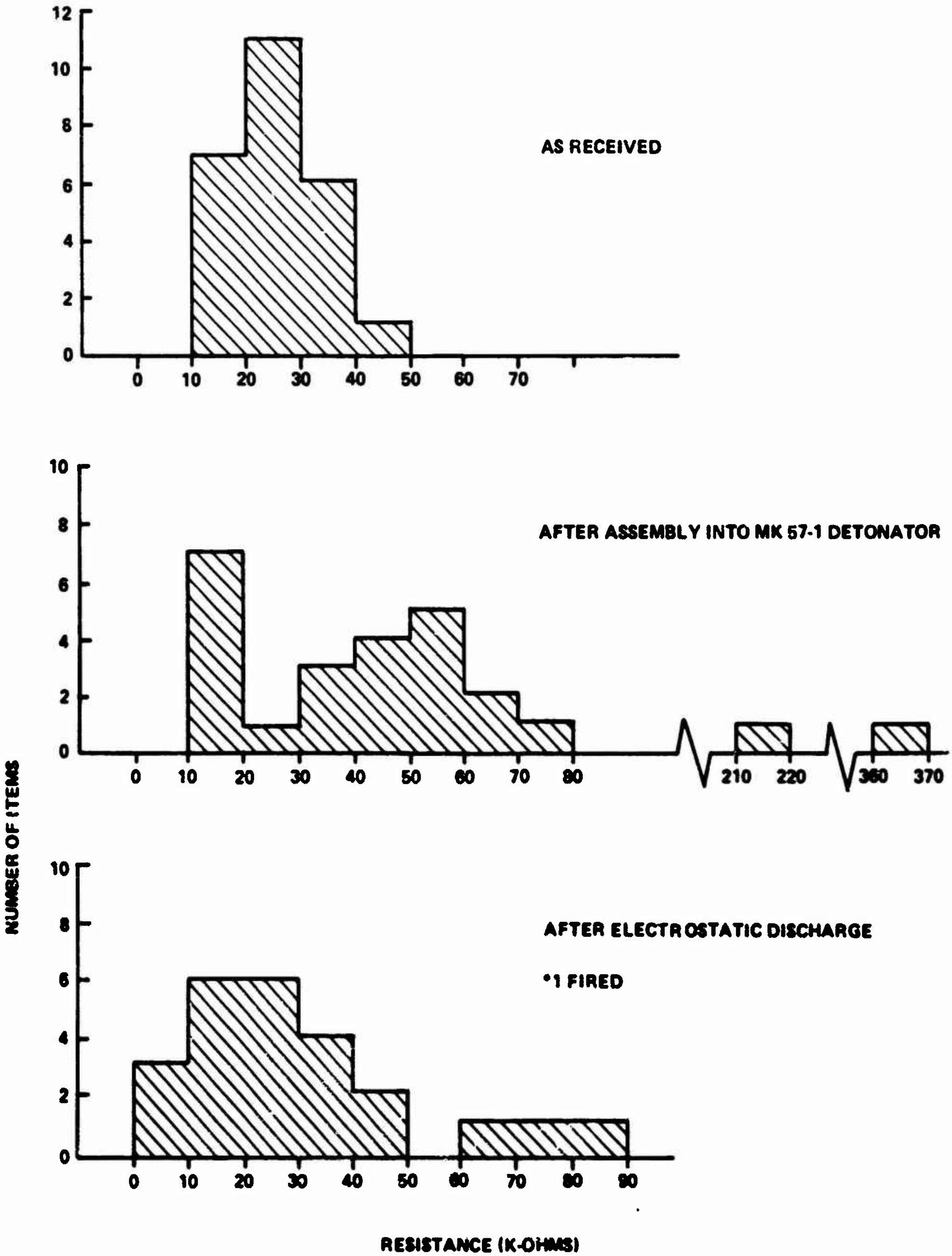



FIG. 13 RESISTANCE CHANGES OBSERVED WITH DETORONIC BLEEDER RESISTOR PLUGS

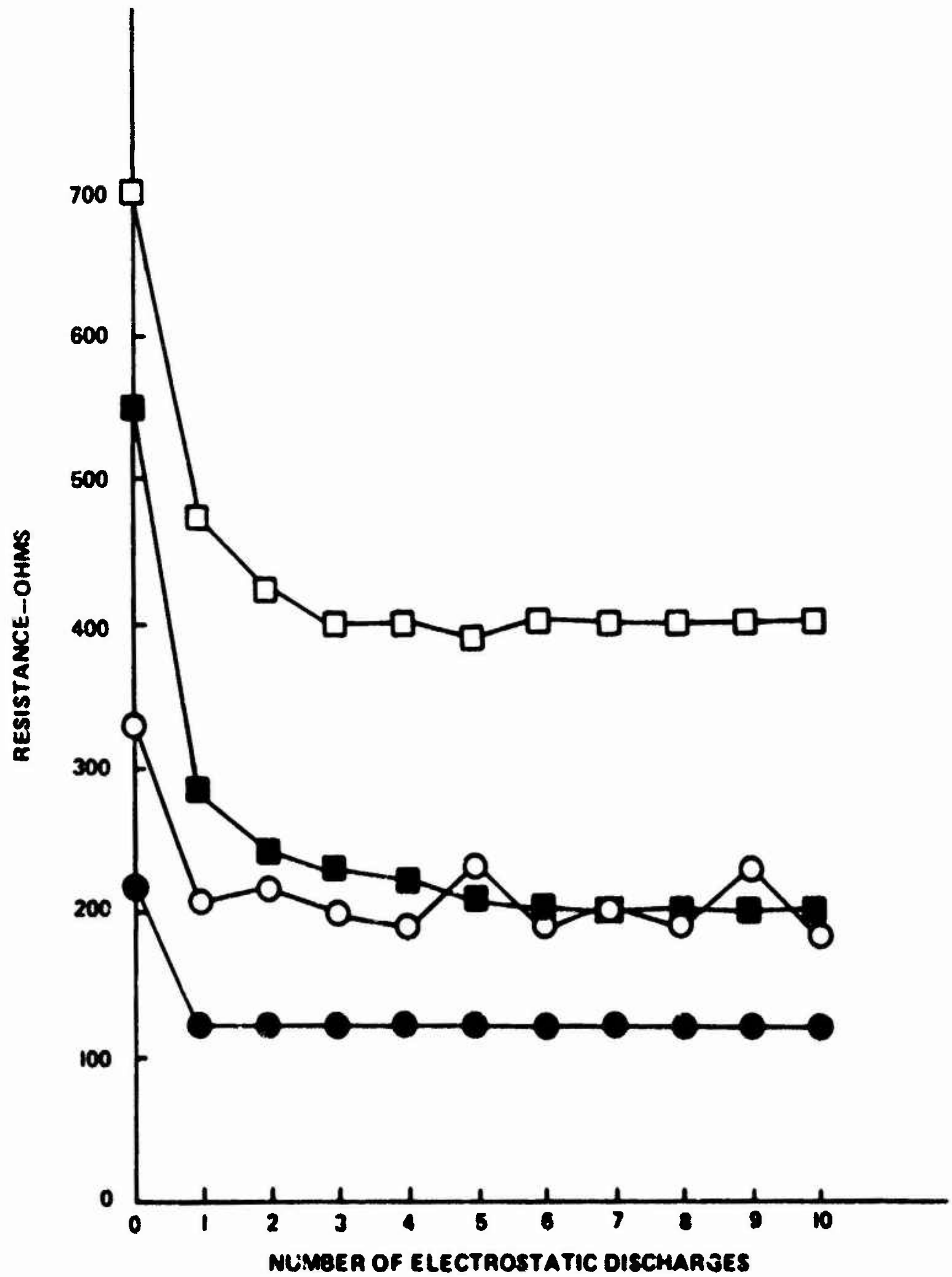
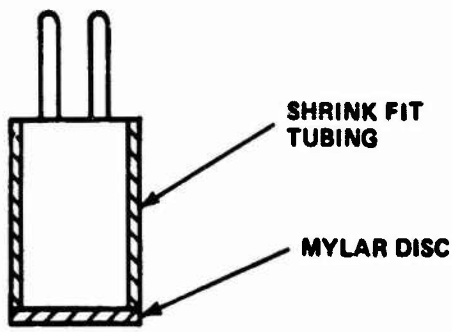



FIG. 14 EFFECT OF MULTIPLE ELECTROSTATIC DISCHARGES ON PIN-TO-CASE RESISTANCE OF MK 57-1 DETONATORS TREATED WITH ELECTRODAG® +501

Syntholvar tubing (#AWG-3 for 0.275" (7mm) dia. cup wetted in butylacetate) can be shrink fitted on the EED. Trim edges with sharp knife to fit EED as shown. This material adds 0.040" (1mm) to dia. of EED. A 2-mil (0.05mm) MYLAR disc, 0.315" dia. (8mm) is used on the output end to complete the electrical isolation




The cup can be completely painted with FORMVAR or an equivalent abrasion resistant insulating coating as an alternate isolation method where space is limited

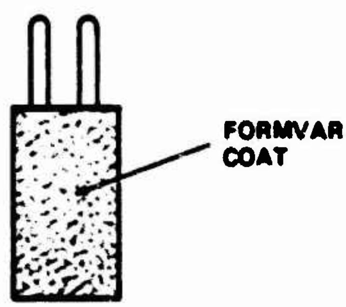



FIG. 15 ELECTRICAL ISOLATION OF EED FROM WEAPON

# APPENDIX A

## STATIC ELECTRICITY PROTECTION BY MEANS OF INTRINSIC RESISTIVE PADDING

### Resistor Padding

Intrinsic protection of an EED can be achieved by preventing any electric fields from developing inside the device. For example, consider the enclosing of the EED in a conducting continuous sheath. The obvious problem of getting energy into the bridgewire via leads is ignored for the moment. This Faraday shield prevents any internal electric fields, and any static discharges are shunted to ground providing complete protection. To allow electrical conduction into the bridgewire, one or two ports can be provided into the aforementioned Faraday shield, with resistive pads or bushings at the points of entry. Although the continuity of the shield has been broken, the effectiveness of the "cage" essentially remains intact. This method of electrostatic protection by means of intrinsic resistive padding appears to be a practical, low cost, simple, and effective technique.

Resistive padding places a resistor across the bridgewire and one or more resistors from the pins or leads to ground. It is the latter resistor ($R_g$) which affords the electrostatic protection while the former resistor ($R_{12}$) bleeds or shunts a small amount of energy from the bridgewire. This is indicated in Figure A1(a) as the three terminal resistor network. If resistance values of 200 to 1,000 ohms are typical, the energy diverted from the bridgewire is negligible. The operation of this protective means can be explained by reference to Figure A1(b) in which the static electricity source is simulated by a charged capacitor that can be discharged through a switch and resistor (Rs) into the EED. In this test procedure, a 5,000 ohm resistor is in series with the discharge loop to simulate contact resistance and switching losses.

Protection is provided by both mismatch and by absorption. In mismatch, the EED never absorbs the energy from the static electricity because it is rejected back to the series resistance. For example, a short circuit or the ideal Faraday enclosure would never accept any energy. As the shield resistance increases, the accepted energy must be absorbed so that the internal gap is by-passed. It is important to note that if no series resistance or loss is provided and full or excess voltage reaches the item, internal discharge is imminent. Mismatch is the major factor in this mode of protection.

### Electrical Aspects of Protection

The circuit shown as Figure A1(a) to model the electrostatic discharge process is idealized. As shown, this "hard" wired system may fail to simulate the poor contact typically made as a charged system is discharged into a resistive network or device. For example, sparking at the inception of switching represents energy loss in excess of that lost in Rs. Starting with a high voltage quality switch that produces no sparking, the switch losses follow

$$W_s = kVIt_s \quad \text{Joules}$$

where k is a constant, $W_s$ is the energy lost at the switch, V is the voltage across the switch, I is the current handled by the switch, and $t_s$ is the switching time. The discharge time constant is 2.5 μs so that switch bounce can be ignored. It is a formidable task to quantify switch losses which also change with circuit configuration and switch degradation. In spite of switch variability, it must be treated as a more efficient energy delivery system than encountered by, for example, a human finger discharge.

Considering the switch near ideal, the voltage that appears across $R_g/2$, in parallel with the internal gap of the device under test, follows

$$v = \frac{R_g/2}{R_g/2 + R_s} \times V \quad .$$

For $R_g/2$ = 500 ohms (i.e., $R_g$ = 1,000 ohms), the voltage delivered to the EED is 2.5 KV. If the internal gap can sustain this voltage without breakdown for a time corresponding to the discharge time constant, then protection has been accomplished. Although the EED is represented as an air gap, there is a series combination of dielectric gaps, including the explosive material, that inhibit breakdown. The intrinsic standoff voltage for an item should be determined so that the voltage division equation has meaning and application. If internal breakdown is precluded, then the resistive pad must absorb an energy of 14 mj.

The shunt resistive circuit across the device offers a stabilization path. Now, charges built up on leads have a natural dissipation or drain mechanism. Current pulses or surges, sometimes generated due to the collapse of magnetic fields and mutual inductance, now have a low resistance path to limit the voltage. For example, a 500 ohm resistance can pass a 1 ampere current spike and limit the voltage to 500 volts. This is not to be considered a regular hazard condition. An unshunted gap in an explosive environment is a vulnerable system and any stabilization offered by a shunt resistance will improve the intrinsic safety.

Thick Film Materials

The conducting materials employed for resistive padding in thick film systems described have certain unusual properties that must be considered for proper design and utilization. Empiricism and proprietary restrictions obscure the fundamental design principles. Thick films use carbon or graphite dispersed in a resin binder. Technical literature describing such mixtures from theoretical aspects are plentiful but unfortunately do not relate to the reduction to practice.

For the case of thick films, it is possible to apply several thicknesses to achieve the desired resistance. Resistances are measured pin-to-pin, if no conducting ferrule is available. For a finished item, the resistance from pin-to-case is the important measurement. Fortunately, resistive padding does not require highly critical resistance control.

The conduction mechanism in the aforementioned dispersed conduction systems is very dependent on the interstitial contact as carbon particles meet carbon particles. Current densities are high in these point contact regions and, during electrical loading, irreversible breakdown.can take place. Fortunately, the decomposition products are carbonaceous and the resulting conductivity is increased after a dissipation surge. The surge performance of a resistor material is very dependent on the stability of the interstices,and this is a common weakness in many of these dispersion conductors.

## Ground Loop Effects in Resistive Padded Devices

The use of resistive padding is a departure from earlier concepts in which a high insulation resistance was required between the bridgewire leads and the housing. If a firing circuit is floating above ground (i.e., has no ground connections) then it is an electrostatic energy storage capacitor and with no drain resistance, can be a hazard condition by itself. A high insulation resistance would, in effect, enhance this hazard. Insulation resistance measurement is a procedure typically employed to guarantee the integrity of the dielectric and is of questionable value except to indicate a short circuit condition.

In the circuit shown as Figure A1(c) a floating firing circuit would not be influenced by the ground through $R_g$. If an accidental ground was developed at one lead of the firing circuit, the EED would be in series with $R_g$ which might be typically 200 ohms. For a 4 ohm bridgewire, only 2% of the firing energy could be delivered to the EED. The possibility of firing the device through a series resistance of $R_g$ is very remote. However, if ground loop currents cannot be tolerated at any level,then a dielectric bushing or varnish coating can insulate the EED housing from ground without any sacrifice in electrostatic protection. All high voltages are still diverted away from the EED to the dielectric gap at the ground location.

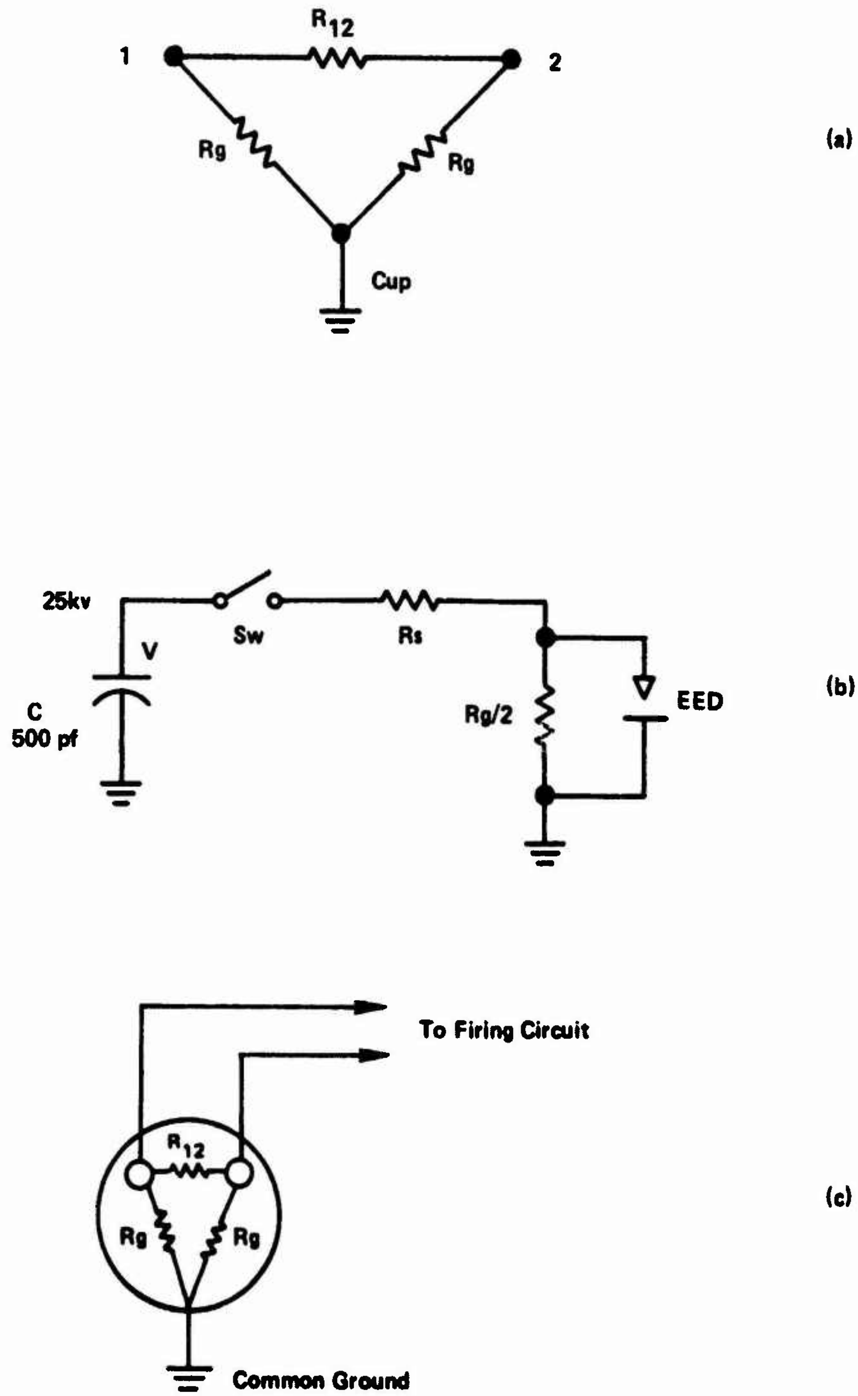



FIG. A1 RESISTIVE PADDING

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